Joint EC/IAEA Training course with Nucleonica , 12-15th Oct., Monaco

RANGE AND STOPPING POWER CALCULATIONS IN NUCLEONICA

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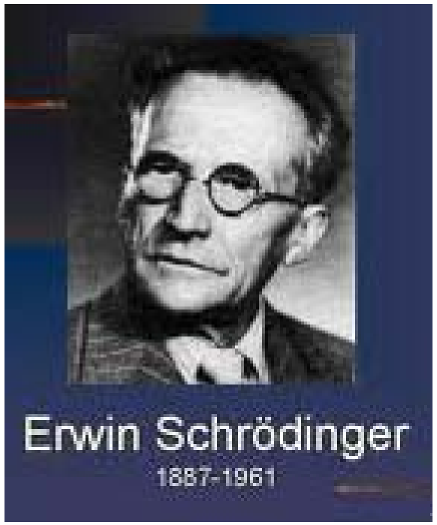
Range & Stopping Power in Nucleonica

Stopping Power; energy loss of energetic particles per unit length in matter.

The range; the mean path length of the particle in the target matter before coming to rest.

Niels Bohr
(1885-1962)

The first calculation of stopping power was done by Bohr in 1913.



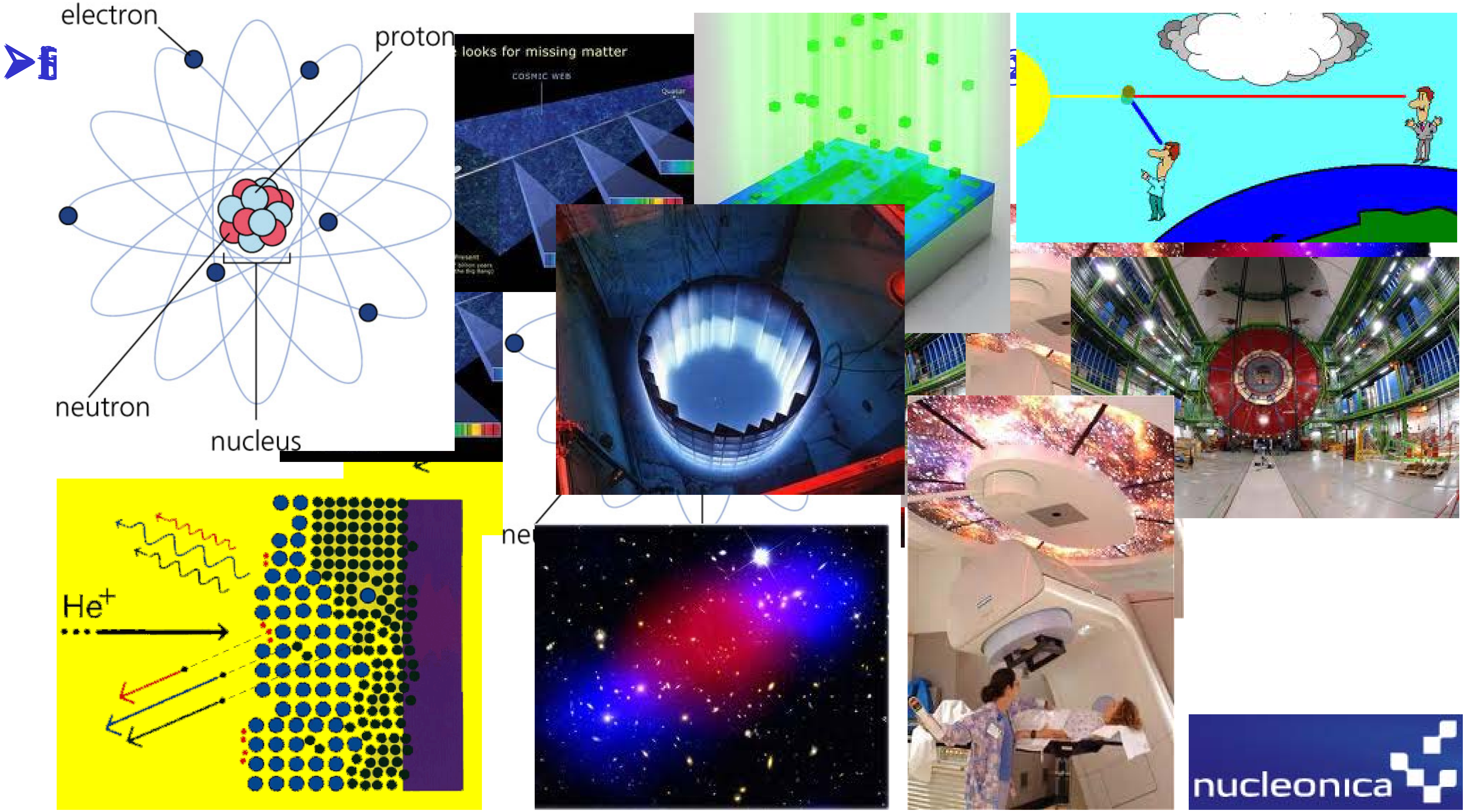
Wave mechanics started in 1926

Hans A. Bethe
1906-2005

First quantum mechanical calculation of stopping power in 1930

Range & Stopping Power in Nucleonica

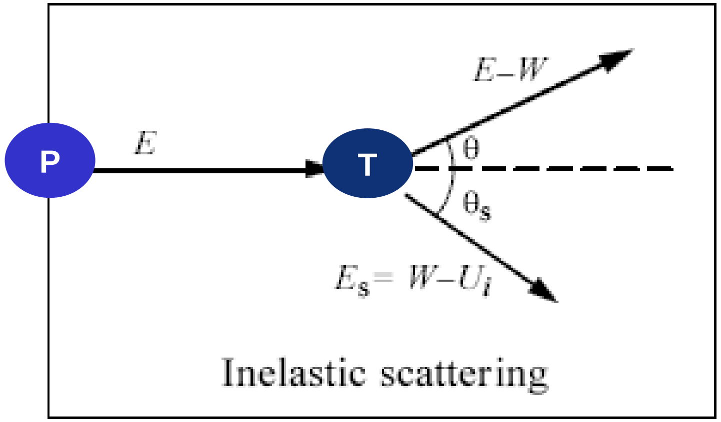
Stopping power has been studied

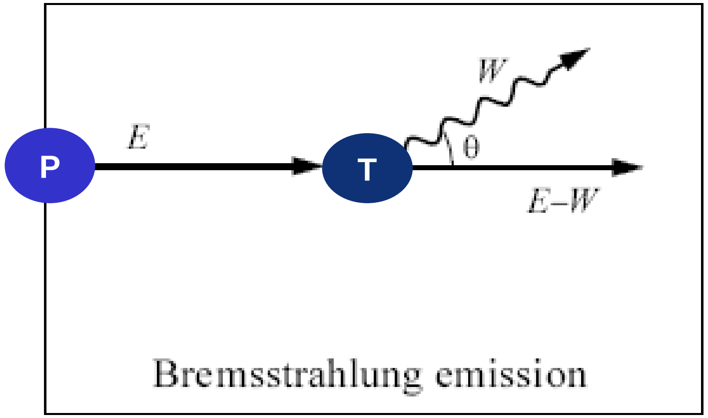


Types of Interactions

I. Inelastic scattering on atomic orbital electrons. It leads to excitations and ionizations of atoms of the medium, and is called "Collisional Stopping Power".

II. Inelastic nuclear scattering. This results in radiation which is known as "Bremsstrahlung", so the stopping power is the "Radiative Stopping Power".





Physics Behind the RANGE Module

- The RANGE module uses the SRIM "engine" for heavy ions, alphas and protons.

- Own codes for the calculations for electron, positron and muon projectiles.

- The interaction of incident electrons with target electrons can be calculated from Bethe’s theory.

- The collisional stopping power of matter is calculated by considering the effective charge approximation.

- For Radiative Stopping Power, RANGE module uses simple ratio:

$$S_{rad}/S_{coll} = ZE/800$$

- Range of the electrons, positrons and muons in matter is calculated by using Continuous Slowing Down Approximation (CSDA):

$$R(E) = \int_{E_{abs}}^{E} \frac{dE'}{S(E')}$$

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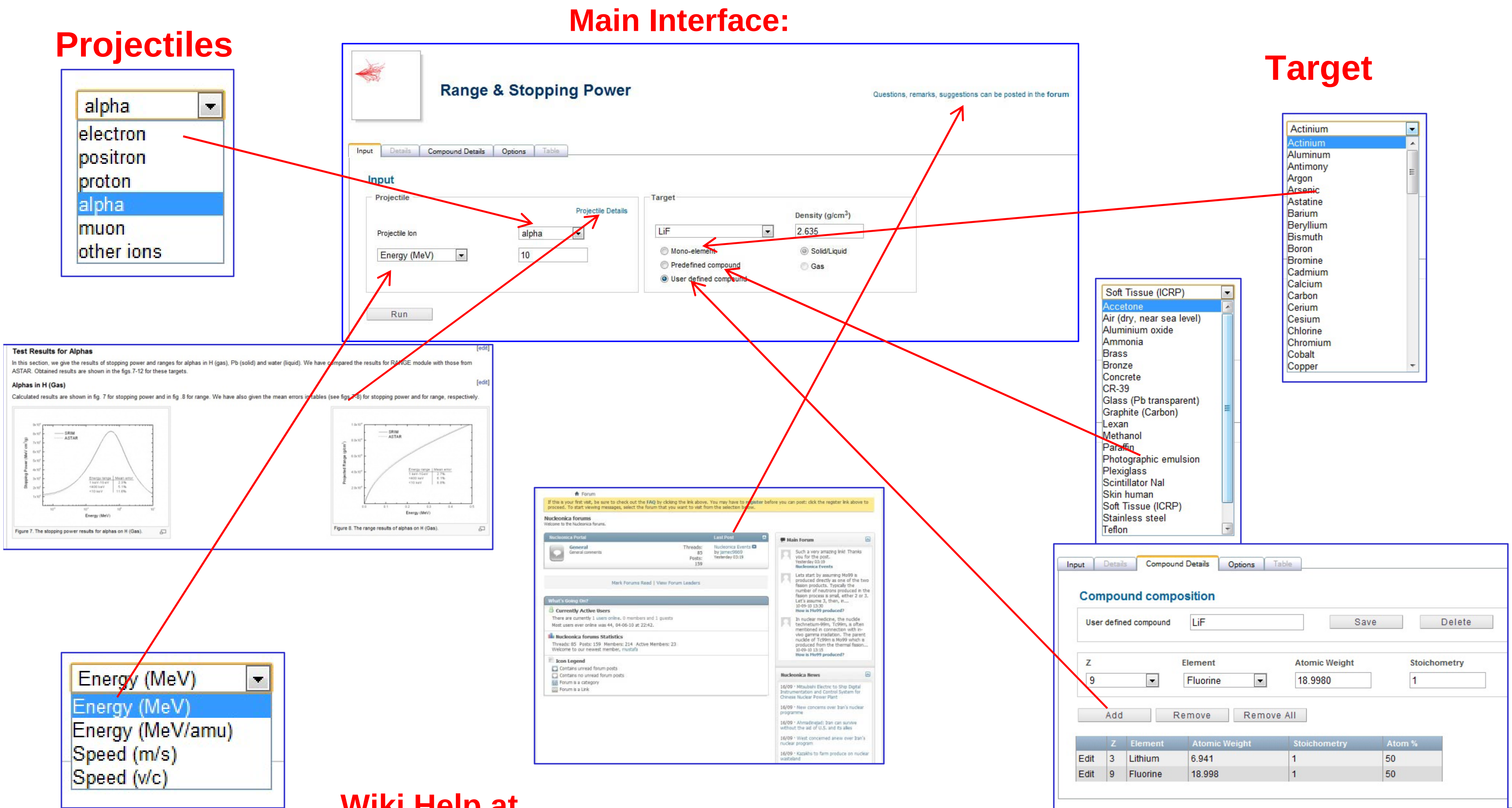

Wiki Help at

http://www.nucleonica.net/wiki/index.php/Help:Range_%26_Stopping_Power

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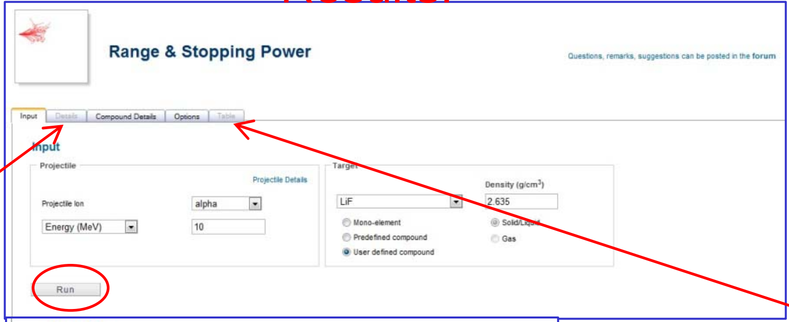
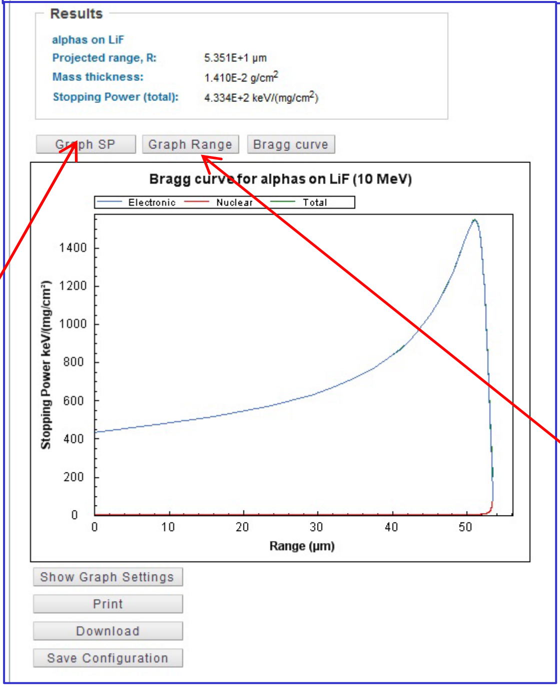
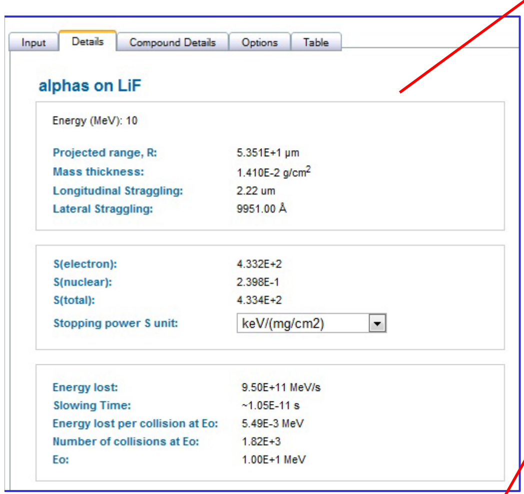
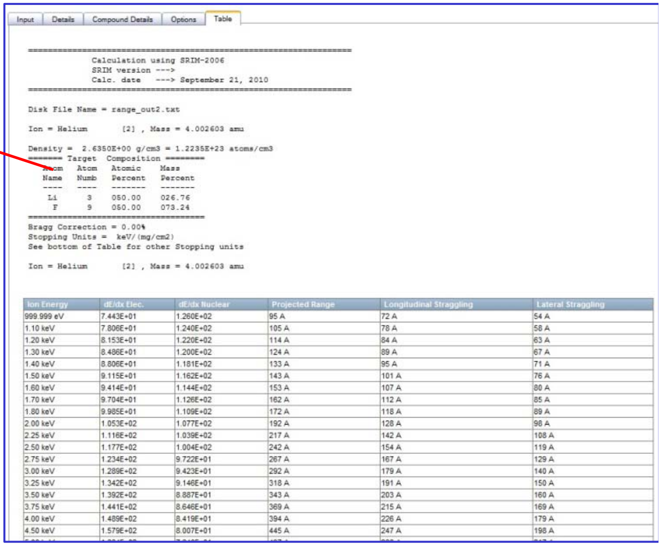
Range & Stopping Power in Nucleonica

Results:





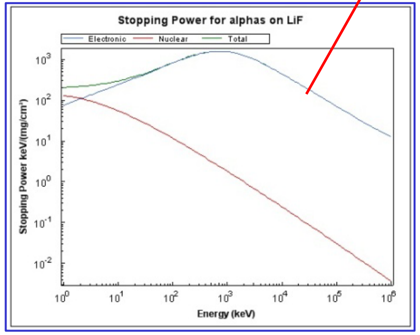


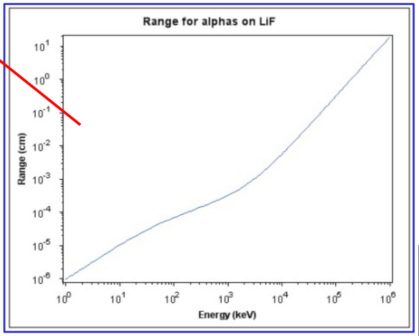


Input | Details | Compound Details | Options | Table

```
=========================================================
            Calculation using SRIM-2006
            SRIM version --->
            Calc. date   ---> September 21, 2010
=========================================================

Disk File Name = range_out2.txt

Ion = Helium      [2] , Mass = 4.002603 amu

Density =  2.6350E+00 g/cm3 = 1.2235E+23 atoms/cm3
======= Target  Composition ========
    Atom   Atom   Atomic    Mass
    Name   Numb   Percent   Percent
    ----   ----   -------   -------
     Li      3    050.00    026.76
      F      9    050.00    073.24
====================================
Bragg Correction = 0.00%
Stopping Units =  keV/(mg/cm2)
See bottom of Table for other Stopping units

Ion = Helium      [2] , Mass = 4.002603 amu
```

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
999.999 eV	7.443E+01	1.260E+02	95 A	72 A	54 A
1.10 keV	7.806E+01	1.240E+02	105 A	78 A	58 A
1.20 keV	8.153E+01	1.220E+02	114 A	84 A	63 A
1.30 keV	8.486E+01	1.200E+02	124 A	89 A	67 A
1.40 keV	8.806E+01	1.181E+02	133 A	95 A	71 A
1.50 keV	9.115E+01	1.162E+02	143 A	101 A	76 A
1.60 keV	9.414E+01	1.144E+02	153 A	107 A	80 A
1.70 keV	9.704E+01	1.126E+02	162 A	112 A	85 A
1.80 keV	9.985E+01	1.109E+02	172 A	118 A	89 A
2.00 keV	1.053E+02	1.077E+02	192 A	128 A	98 A
2.25 keV	1.116E+02	1.039E+02	217 A	142 A	108 A
2.50 keV	1.177E+02	1.004E+02	242 A	154 A	119 A
2.75 keV	1.234E+02	9.722E+01	267 A	167 A	129 A
3.00 keV	1.289E+02	9.423E+01	292 A	179 A	140 A
3.25 keV	1.342E+02	9.146E+01	318 A	191 A	150 A
3.50 keV	1.392E+02	8.887E+01	343 A	203 A	160 A
3.75 keV	1.441E+02	8.646E+01	369 A	215 A	169 A
4.00 keV	1.489E+02	8.419E+01	394 A	226 A	179 A
4.50 keV	1.579E+02	8.007E+01	445 A	247 A	198 A





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Range & Stopping Power in Nucleonica

Wiki Help:

Range Calculations [edit]

Most of the transport calculations and Monte Carlo simulations for the calculation of Range are based on the so-called Continuous Slowing Down Approximation (CSDA). In this approximation, it is assumed that the particle losses its energy in a continuous way and at a rate equal to the stopping power. Since the stopping power is the energy loss of projectile per unit path, CSDA range (or Bethe range) is calculated by

$$R(E) = \int_{E_{abs}}^{E} \frac{dE'}{S(E')}$$

where E_{abs} is the energy where particle is effectively absorbed. CSDA range is the path length traveled by the particle and since energy-loss fluctuations are not considered, CSDA range is always higher than projected range (R_p) which is the distance between the point where particle enters the stopping medium and the point where particle is absorbed (or come to rest). It becomes important when the projectile's energy is low enough.

SRIM uses PRAL (**P**rojected **R**ange **AL**gorithm) [6] equations for calculating projected range. To second order it involves iterating the difference equation

$$R_p(E_0 + \Delta E_0) = R_p(E_0) + \left[\frac{4E^2 - (2E\mu S_n + \mu Q_n)R_p(E_0)}{4ES_t - 2\mu Q_n}\right]\frac{\Delta E_0}{E}$$

Test Results for Protons [edit]

We calculated the stopping powers and ranges of H (Gas), Pb (solid) and water (Liquid) for protons and compared the results with PSTAR.

Protons on H (Gas) [edit]

As can be seen in fig.1, overall agreement with PSTAR is quite good. Comparing the RANGE module's results with PSTAR, the overall mean error in energy range from 1 keV to 1 GeV is 0.8 %, mean error is 1.8 % in energies below 400 keV and mean error in energies below 10 keV is 2.5 %.

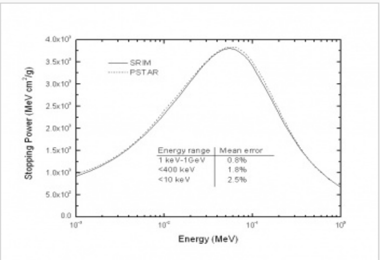

Figure 1. The stopping power results for protons in H (Gas).

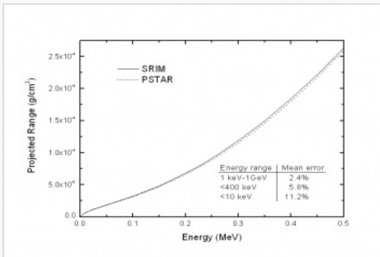

Figure 2. The range results of protons in H (Gas).

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nucleonica [wiki]

Help:Range & Stopping Power

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Range and Stopping power

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Range & Stopping Power in Nucleonica

The RANGE module:

- provides a user-friendly interface for quick and accurate calculations on the range and stopping powers of charged particles.
- can calculate SP and Range for electrons, positrons, protons, alphas, muons and heavy ions in a variety of different natural elements, pre-defined and user-defined compounds.
- give freedom to the user for selecting the energy and stopping power units.
- provides high quality graphs for SP and Range.
- can be used in the Nucleonica scripting language.
- Test results show agreements of less than 5% for protons and alphas, less than 10% for electrons and positrons, and less than 7% for muons for the total stopping powers and the CSDA Ranges. The Range module uses SRIM for heavy particles with a known accuracy of less than 5%.

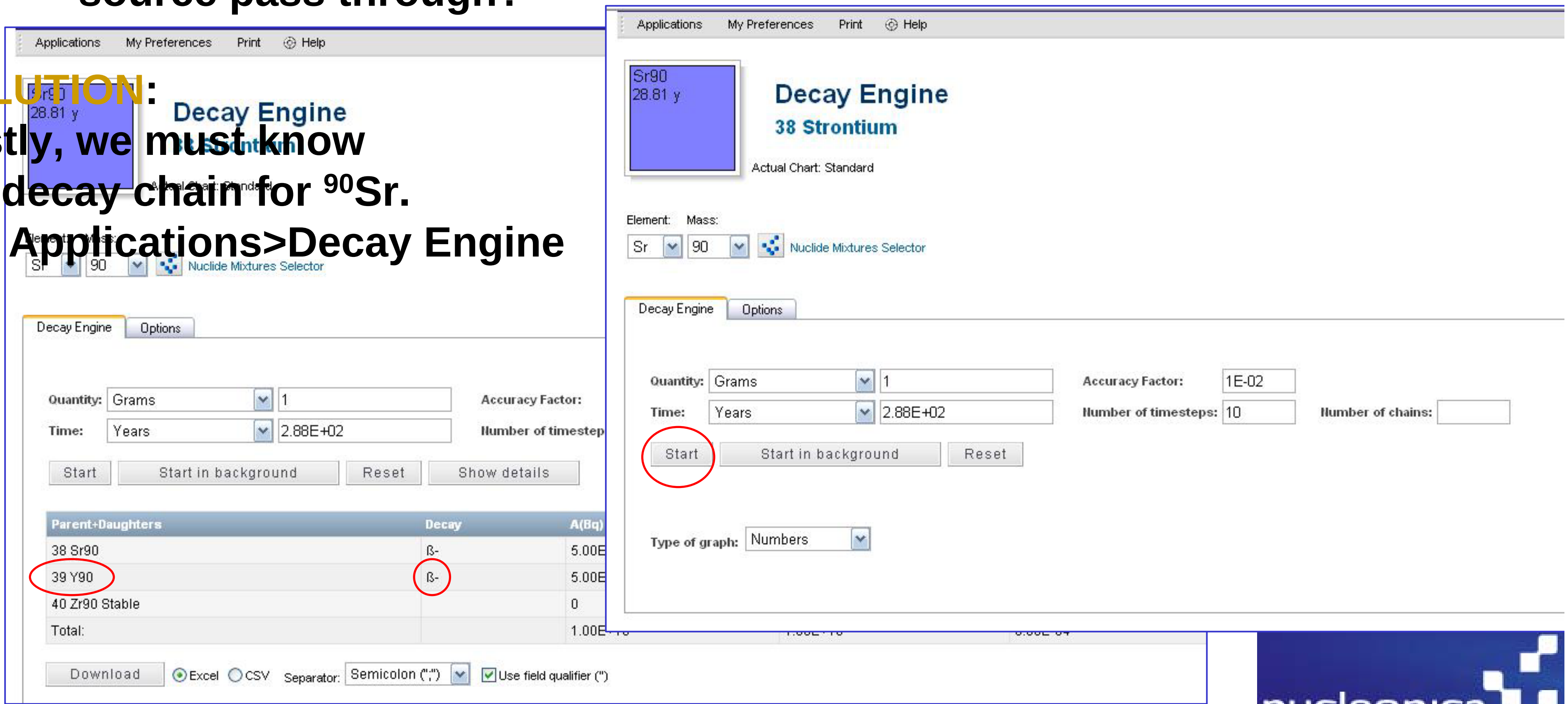
EXERCISES

Q1: What must be the minimum thickness of a shield made of (a) Plexiglas and (b) aluminum in order that no beta rays from a ^{90}Sr source pass through?

SOLUTION:

Firstly, we must know the decay chain for ^{90}Sr.

Go, Applications>Decay Engine



Range & Stopping Power in Nucleonica

What is the energies of beta rays from ^{90}Sr and ^{90}Y?
Go Data>Nuclide Datasheet

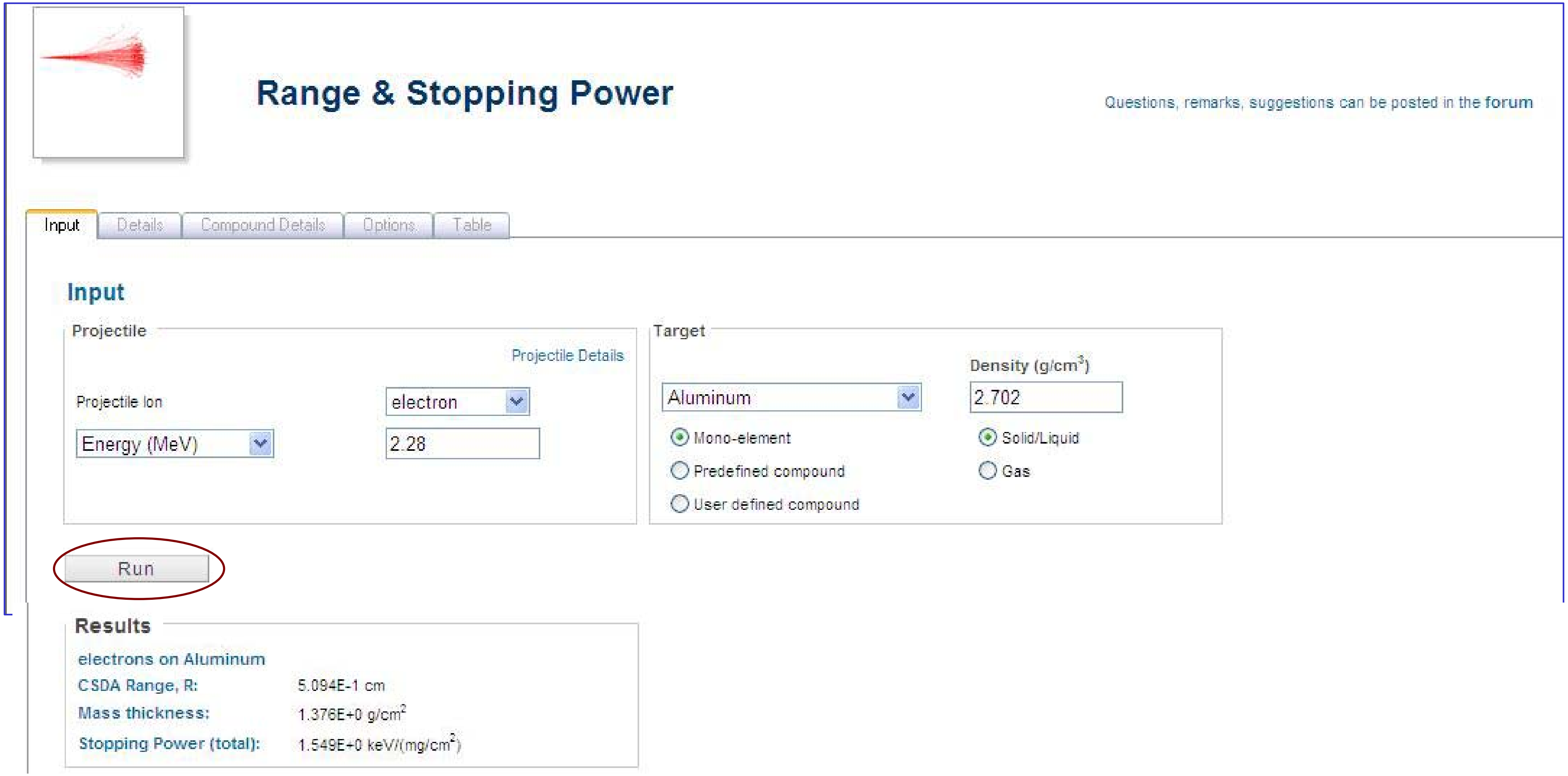
Element: Sr Mass: 90

Datasheet | Description | Derived Data | Average Cross Sections | Radiations | Prompt Gamma | Select Print Outputs

» Reference Data Notes

Density	2.64 g/cm^3		
Mass Excess	-85941.604 (± 2887) keV		
Atomic Mass	89.907737888 (± 3099) u		
Half-life	28.79 (± 6) y		
Spin	0 ħ		
Parity	+		
Binding Energy	8.69590 MeV/nucleon		
Abundance	-		
Effective Dose Coefficient Inhalation	1.6E-07 (Sv/Bq)		
Effective Dose Coefficient Ingestion	2.8E-08 (Sv/Bq)		
Mean Decay Energies			
Alpha	0 (Mev)		
Electron	174 (keV)		
Photon	0 (keV)		
Type of decay	Branching Ratio	Decay Energy,Q	Daughters
ß-	1	0.546 (MeV)	39 Y 90

Range & Stopping Power in Nucleonica



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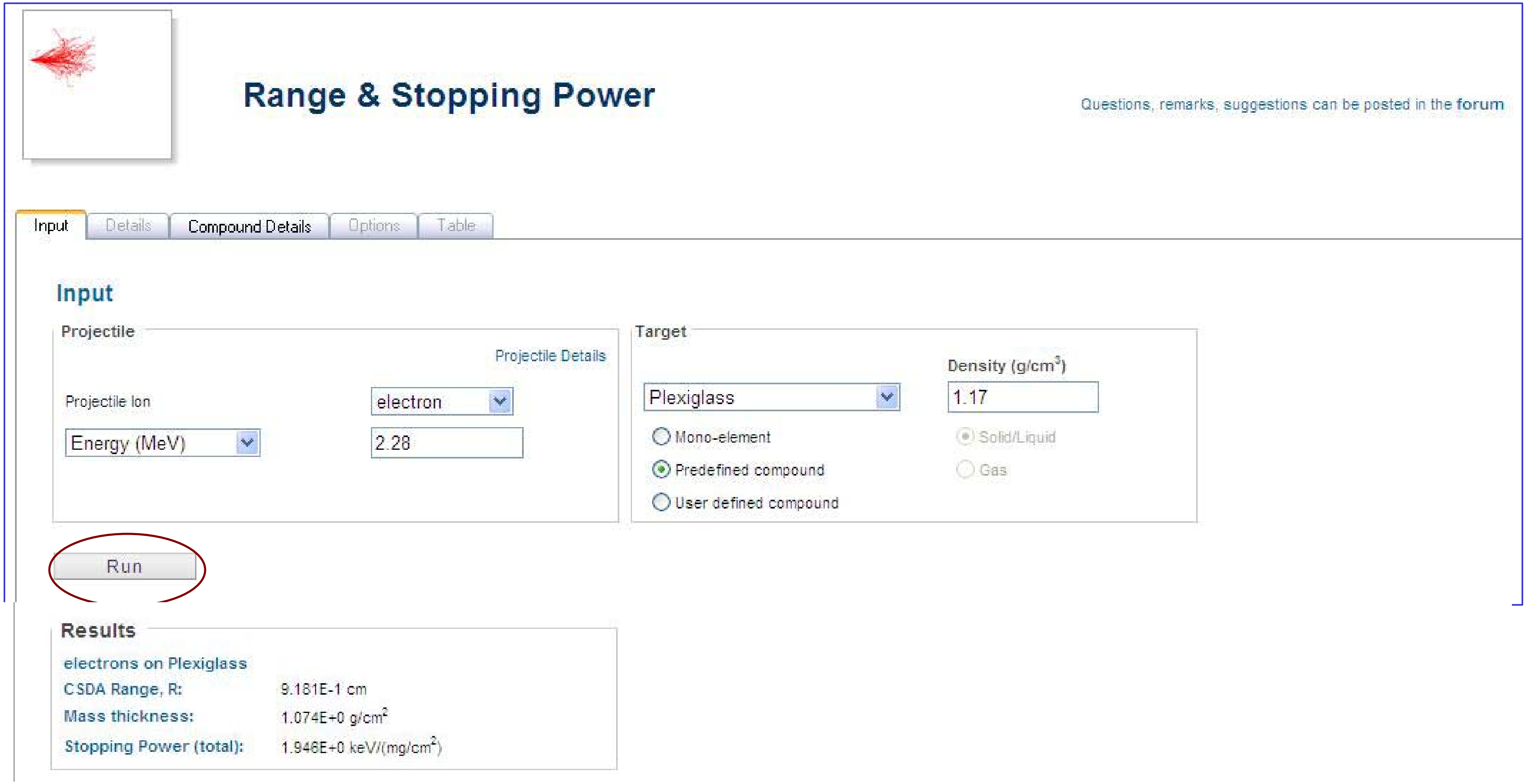
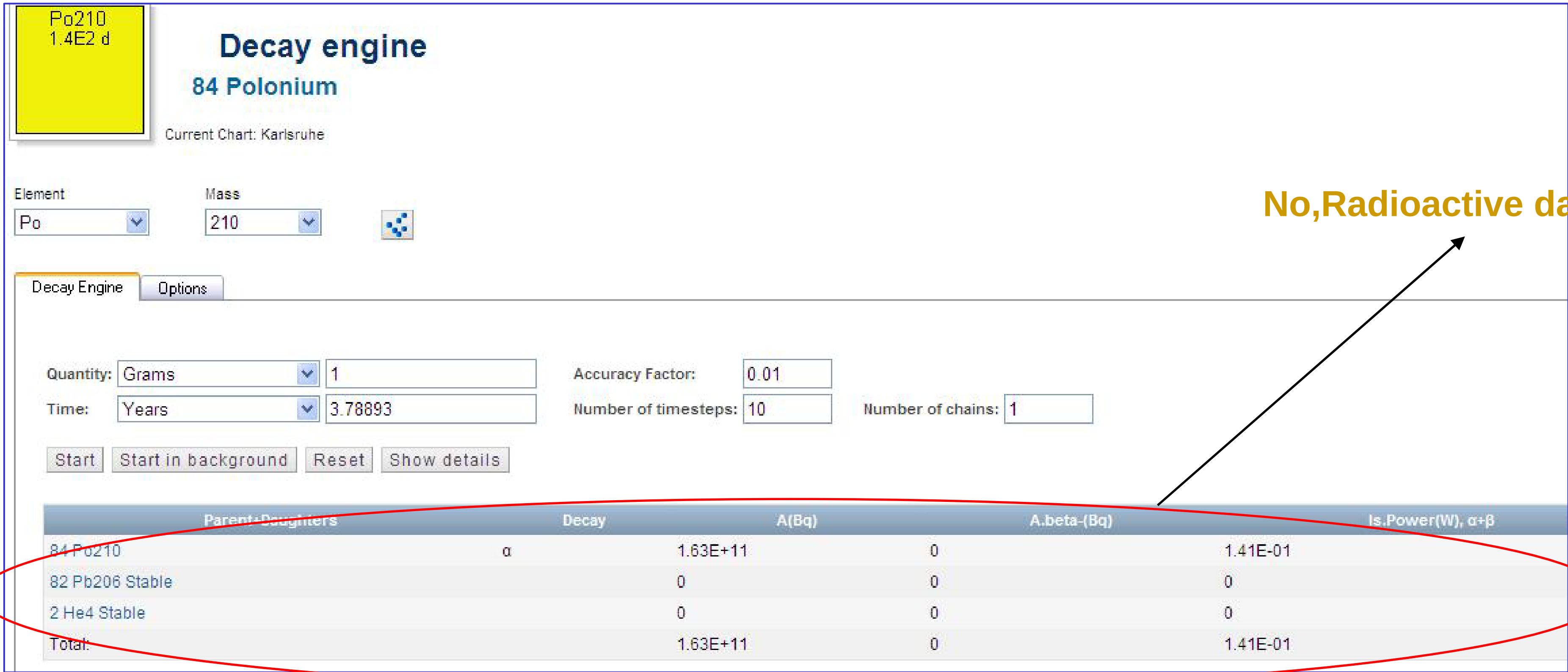


Range & Stopping Power in Nucleonica

Q2:What thickness of aluminum foil is required to stop the alpha particles from ^{210}Po?

Hint: Check the decay chain of Po-210, then find the maximum energy of the alpha particles emited in the chain.

SOLUTION:



No,Radioactive daughter

Range & Stopping Power in Nucleonica

Data>Nuclide Datasheet

Element: Po Mass: 210

Reference Data | Description | Derived Data | Cross Sections | Radiations | Prompt Gammas | Select Print Outputs

» Reference Data Notes

Density	9.20 g/cm^3		
Mass Excess	-15953.071 (± 1242) keV		
Atomic Mass	209.982873673 (± 1333) u		
Half-life	138.388 (± 4) d		
Spin	0 ħ		
Parity	+		
Binding Energy	7.83435 MeV/nucleon		
Abundance	-		
Effective Dose Coefficient Inhalation	4.3E-06 (Sv/Bq)		
Effective Dose Coefficient Ingestion	1.2E-06 (Sv/Bq)		
Mean Decay Energies			
Alpha	5.40752 (Mev)		
Electron	9.32726E-05 (keV)		
Photon	0.00972462 (keV)		
Type of decay	Branching Ratio	Decay Energy,Q	Daughters
α	1	5.40745 (MeV)	82 Pb 206

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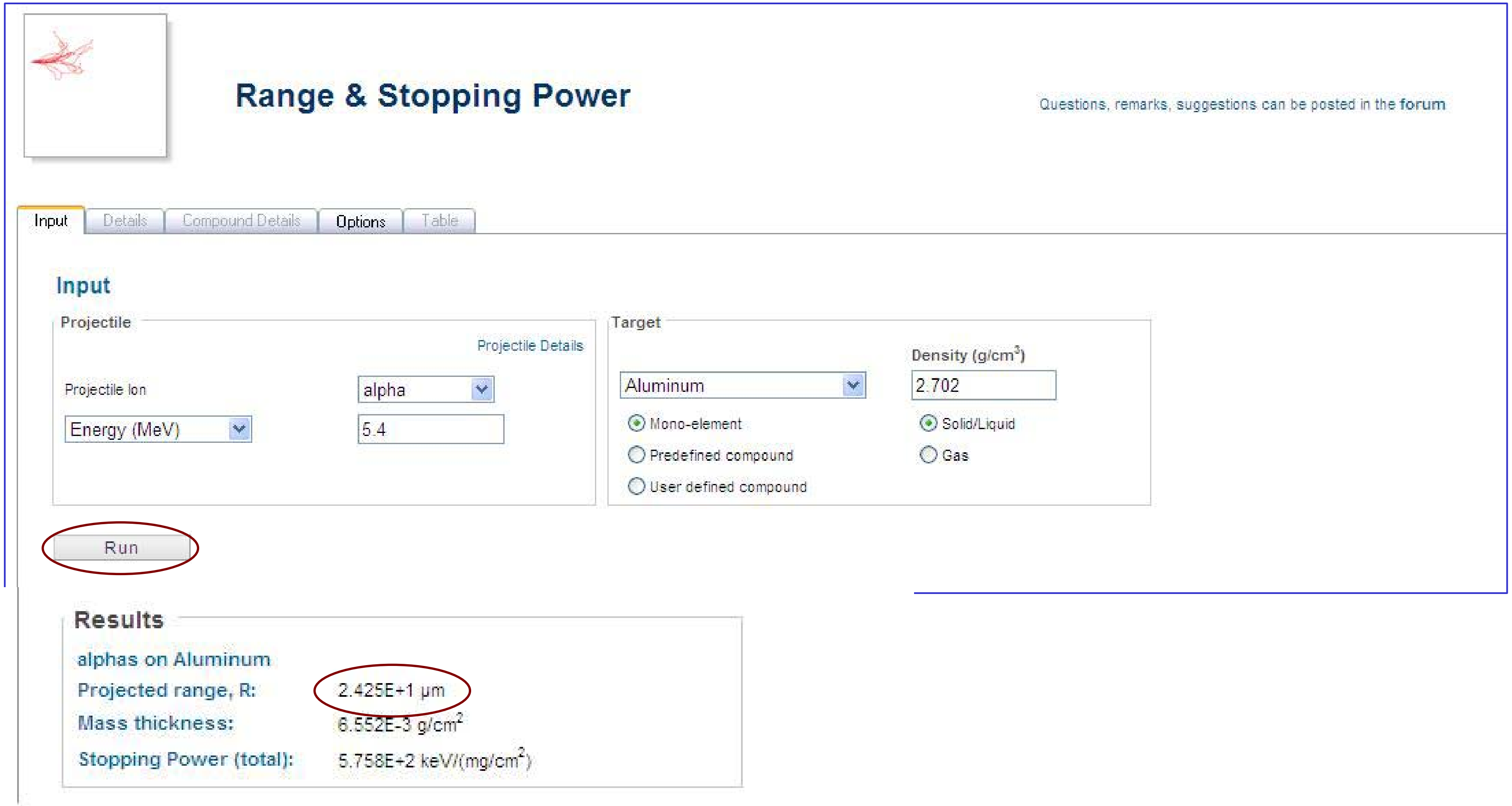
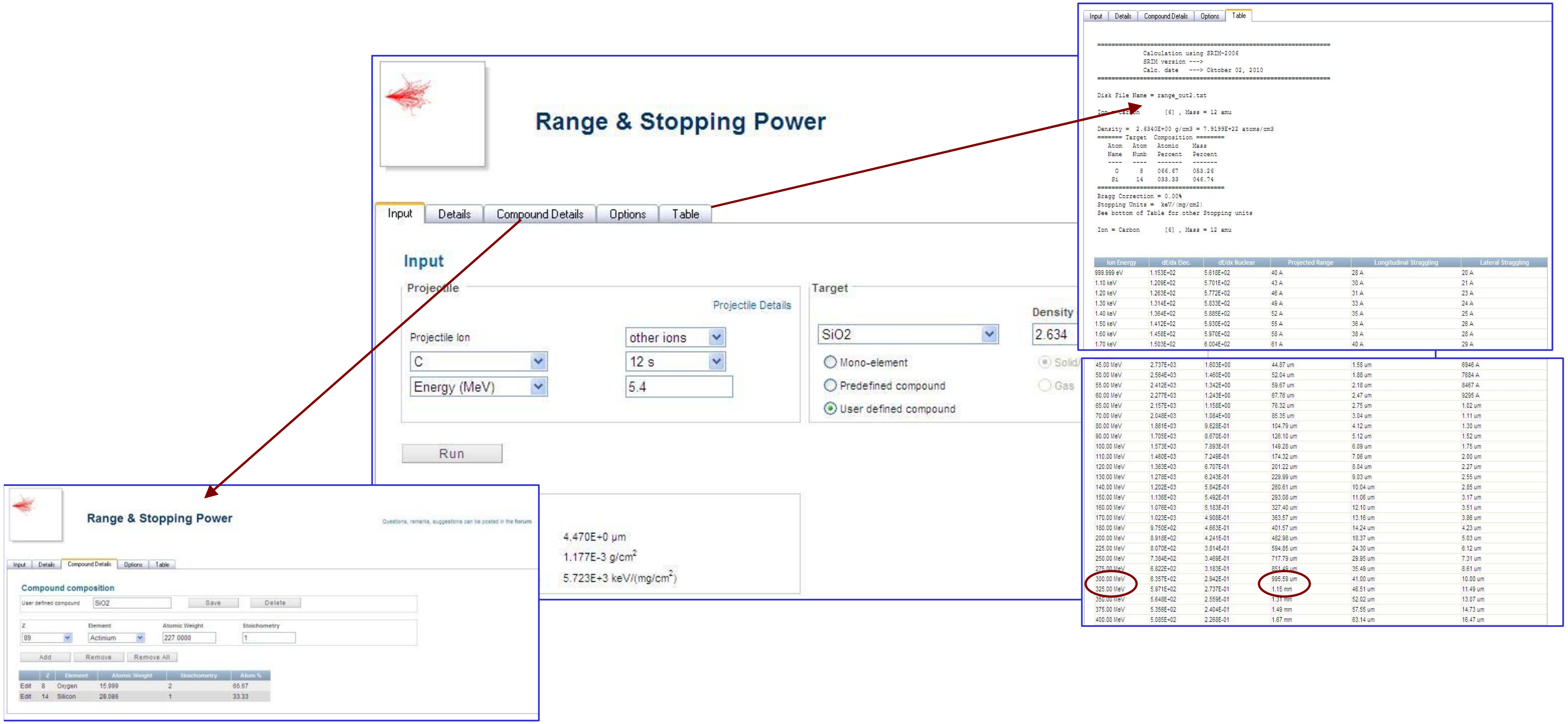
Range & Stopping Power in Nucleonica



Range & Stopping Power in Nucleonica

Q3: What are the energies of ^{12}C ions to implant to 1mm depht in SiO_2 sample?

SOLUTION



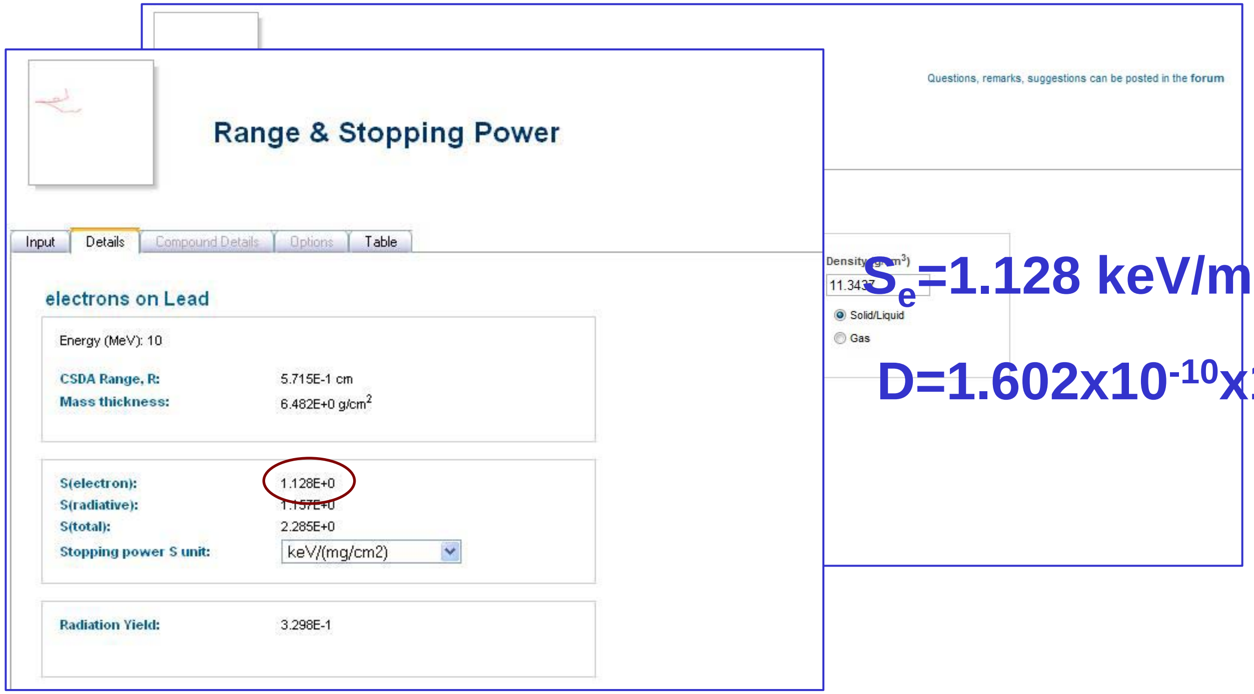
Range & Stopping Power in Nucleonica

Q4: Consider the case of fluence of 10^{10} /cm^2 10 MeV electrons incident on a Pb layer 1mm thick. Calculate the mean dose deposited by electrons.

SOLUTION

Mean dose deposited by the electrons is given as $D=1.602\times10^{-10}\times S_e\times\Phi$

Here S_e is collisional stopping power in units MeV/g/cm^2 and Φ is the fluence in 1/cm^2. So, dose can be obtained as Gy.



S_e=1.128 keV/mg/cm^2 (MeV/g/cm^2)

$D=1.602\times10^{-10}\times1.128\times10^{-10}$= 1.807 Gy

Thanks!

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